Precision Apiculture:

Continuous Beehive Monitoring

Bio-Geo Spatial Technologies Seminar

Evan Henry
October 23rd

Presentation Overview

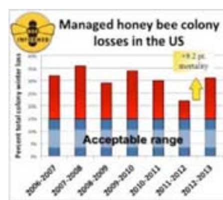
- Background:
  - Pollination & Precision Apiculture
- Beehive Sensor Network
  - Hardware
  - Software
- Effects of Electromagnetic Radiation on Beehive Health
  - Results of 2015 Field Season
- Conclusions and Outlook on Hive Sensors

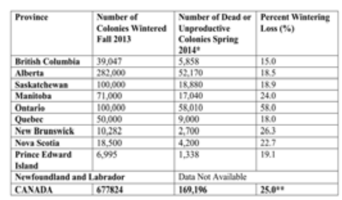
Pollination: Angiosperm Plant Reproduction

- Pollen: Gamete cells
- Enables fertilization, reproduction, and fruiting
- 200,000 species of animal pollinators
- 1 in 3 bites of food derived from pollination by honeybees
- Global honeybee pollination in 2005 valued at $200 billion.

Colony Collapse Disorder

- Characterized by a disappearance of worker bees inside the hive
- Translates to $15 billion of lost crops in the U.S.A.





Province	Number of Colonies Wintered Fall 2013	Number of Dead or Unproductive Colonies Spring 2014*	Percent Wintering Loss (%)
British Columbia	39,047	5,858	15.0
Alberta	282,000	52,170	18.5
Saskatchewan	100,000	18,880	18.9
Manitoba	71,000	17,040	24.0
Ontario	100,000	58,010	58.0
Quebec	50,000	9,000	18.0
New Brunswick	10,282	2,700	26.3
Nova Scotia	18,500	4,200	22.7
Prince Edward Island	6,995	1,338	19.1
Newfoundland and Labrador		Data Not Available	
CANADA	677824	169,196	25.0**

Precision Apiculture:

- Beehive data difficult to collect:
  - Little quantitative data exists on hive conditions and observations from hive inspections are not often integrated into research (Mezquida and Martinez, 2009)
- Results in methodological shortcomings:
  - In Colony Collapse Disorder (CDD) research, hives are sampled only after an incident is reported (USDA 2008).
- Solution: In-hive sensor systems

Precision Apiculture

- Definition:
  - "Precision Beekeeping (PB), a sub-branch of Precision Agriculture, is an apiary management strategy based on the monitoring of individual bee colonies to minimise resource consumption and maximise the productivity of bees." (Zacepines et al, 2015)
- Main parameters tested:
  - Climatic (temperature, humidity, air pressure)
  - Hive weight
  - Acoustics
  - Gas concentrations

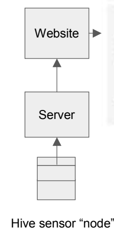
Table 1. Summary of research using continuous monitoring methods. 22

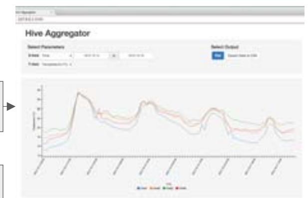
Parameter	Method	Location	No. of replicate colonies	Duration of hourly datasets	Reference
Weight and temperature	Mechanical balance and in-hive mercury thermometers	Field	1	1 year; hourly during the day	Gates (1914)
Weight	Mechanical balance	Field	2	12 days	Hambleton (1925)
Weight	Electronic balance	Field	1	1 month	Buchmann and Thoenes (1990)
Weight	Electronic balance	Field	2–4	16 months	Meikle et al. (2006, 2008)
Temperature	Electric thermocouples	Insulated room	1	5 months; hourly during the day	Phillips and Demuth (1914)
Temperature, $[O_2]$ and $[CO_2]$	Electric thermocouples, metabolic chamber with extracted air passed through external detectors	Field	1	3 days	Milner (1921)
Temperature	Extracted air passed over thermometer	Field	1	Approx. 5 days	Southwick and Mugaas (1971)
Temperature, $[CO_2]$, no. of fanning bees	In-hive mercury thermometers, extracted air passed through external detectors	Not stated	1	52 h	Seeley (1974)
Temperature, $[O_2]$, no. of fanning bees	Metabolic chamber with extracted air passed through external detectors	Laboratory	Not stated	Series of 24–48-h experiments over 14 months	Kronenberg and Heller (1982)
Temperature, $[O_2]$ and $[CO_2]$	Extracted air passed through detectors	Field	10	Not specified, some periods of at least 12 h	Southwick and Moritz (1987)
Temperature, $[O_2]$ and $[CO_2]$, humidity	In-hive temperature sensors, extracted air passed through gas detectors	Field and laboratory	Not stated	18 weeks	Van Nerum and Buelens (1997)
Temperature	In-hive sensors	Field	8	2 weeks	Jones et al. (2004)
Temperature, humidity	In-hive sensors	Field	3 (incl. empty control)	4 days	Human et al. (2006)
Temperature	In-hive sensors	Field	14	1 year	Stalidzans and Berzonis (2013)
Vibration	In-hive sensors	Field	2	Approx. 8 months	Bencsik et al. (2011)
Acoustics, temperature, relative humidity	In-hive sensors	Field	3	270 h	Ferrari et al. (2008)
Acoustics, temperature	In-hive sensors	Field	10	Approx. 1 year	Atauri Mezquida and Llorente Martinez (2009)
Forager traffic	Hive entrance sensors	Field	1	23 days	Burrill and Dietz (1981)
Forager traffic	Hive entrance sensors	Field	40	9 days	Danka and Beaman (2007)
Forager traffic	RFID tags and entrance	Field	2	10 trials of up to	Schneider et al. (2012)

W.G. Meikle and N. Holst

Platform Architecture:

1. Hive Sensor - Server:
   a. ZeroMQ websockets
   b. "middleware"
   c. asynchronous communication
   d. support ≤ 253 nodes
2. Server: Data Storage
   a. MongoDB Database
   b. NoSQL
3. Server - Website





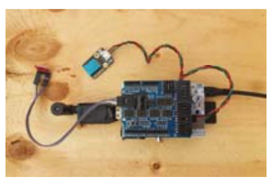
Continuous Beehive Monitoring Hardware

Sensor Components: ~$100

- Raspberry Pi (microcontroller)
- DHT22 Temperature and Humidity Sensor
- PLMC15 Omnidirectional Microphone

Server: Intel Atom D525 / Thinkpad t530

-Linux Debian OS



Software & Demonstration

- 2 pieces of software run simultaneously:
  a. Server software
     - continuously "listening" for hive sensors
  b. Hive sensor software
     - continuously sampling DHT22 sensor and microphone and sending to server

- Server software: "hive-aggregator.py"

- Hive-sensor software: "hive-node.py"

Audio Signal Processing:

1. From a 3 second audio recording
2. Amplitude calculation (dB):
   a. Fast fourier transform
      i. dBm = 20*log(amplitude)
3. Dominant frequency calculation:
   a. Fast Fourier transform
   b. Create histogram of frequency distribution
   c. take median

Fourier Transform animation

Research Objectives: Effects of Electromagnetic Radiation (Wi-Fi 2.4GHz) on Beehives

A Precautionary Study:

-Wireless sensor network useful in precision apiculture

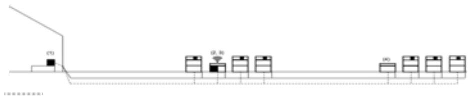
Effects of EMR on animals: Varying results

- Interferes with navigation in migratory robins
  - Magnetite Fe3O4 is used in magnetoreception in robbins and honeybees
- Reproduction, spatial memory in insects
- "Electromagnetic Hypersensitivity" in humans

2.4Ghz Justification: no research exists on its effects on honeybees, it is used in

Experimental Methods:

- 2.4GHz (Wi-Fi) exposed to treatment hives (n=3) for 72 hour periods during September and October, 2015.
- Varroa sample
- Honey frame photo analysis



: Ethernet cable

Wi-Fi Intensity Maps

- Device: RF Spectrum Analyzer
- n > 300

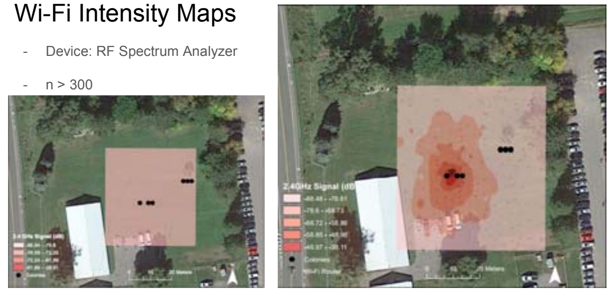


Fig 1, 2: Map of apiary without Wi-Fi Signal (left), and with (right).

Results: Climate Data

External Climate Correlation r^2	Temperature	Humidity
Control Hives	0.86	0.09
Treatment Hives	0.77	0.09

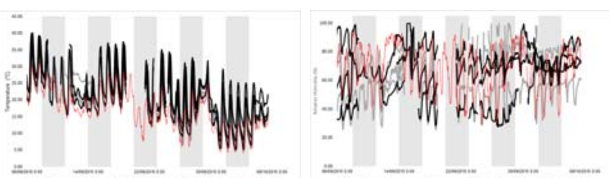
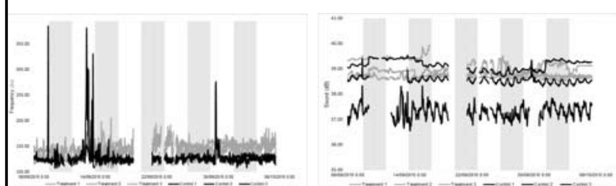


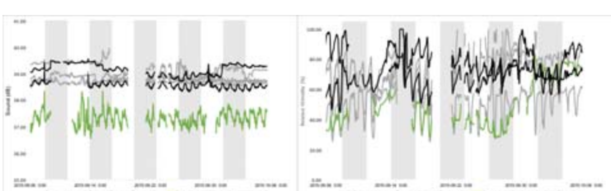
Fig 1, 2: Hourly averages of experimental data. Gray shaded areas represent 2.4Ghz exposure. External temperature and humidity data are represented in red and from the Trudeau Weather Station, Dorval, QC.

Results: Acoustic Data



Figures 3, 4: Hourly averages of experimental data. Gray shaded areas represent 2.4Ghz exposure.

Outlier: Control Hive 1



Varroa destructor: Honeybee parasite

- Varroa mite

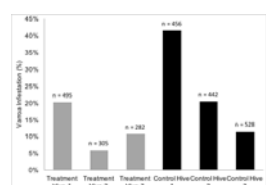


Fig 1. Per hive *Varroa destructor* infestation rate, honeybee sample size reported on graph.

Honey Frame Photo Analysis

- Honey supers extracted from all hives July 25th
- Track rate of honey production

Fig 1. Measuring pixel area using ImageJ

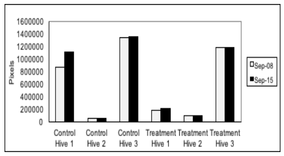


Fig 2. Frame photo analysis of 3honey super, area of capped honey in pixels.

Measuring effect of EMR: Data analysis

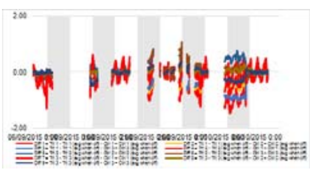
Normalization formula:

$$Diff_{(n,m)i} = \left(Trt_{(n)i} - \overline{Trt_{(n)}(off)}\right) - \left(Ctrl_{(m)i} - \overline{Ctrl_{(m)}(off)}\right)$$

where $Diff_{(n,m)i}$ is the difference between nth treatment and mth control for the ith record; $Trt_{(n)i}$ is the measured parameter for the nth treatment and ith record; $Trt_{(n)}(off)$ is the average measured parameter for the nth treatment when Wi-Fi was off;

$$\begin{cases} \overline{Diff_{(n,m)}(on)} = TrtEffect_{(n,m)} \\ \overline{Diff_{(n,m)}(off)} = 0 \end{cases}$$

Data analysis results: Sound



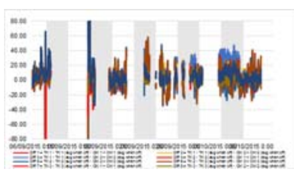
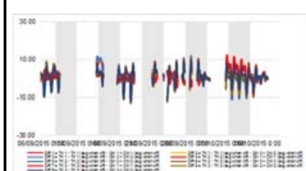


Fig 1, 2. Normalized graphs of frequency data(left) and amplitude (right). Data containing outlier hive (Control 1) highlighted in red

Data Analysis Results: Climatic Conditions



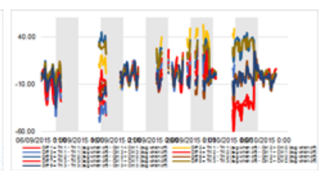


Fig1, 2. Normalized graphs of temperature (left) and humidity (right). Data containing Varroa infested hive (Control 1) highlighted in red

Results

	Temp (C)		Humid (%)		Sound (dB)		Sound (hz)	
	St.dev	Mean	St.dev	Mean	St.dev	Mean	St.dev	Mean
Diff 1	3.85	2.90	18.57	-9.80	21.41	-0.65	21.41	14.02
Diff 2	4.35	2.10	20.95	15.09	0.27	-0.33	15.04	13.44
Diff 3	4.50	2.97	17.01	-11.61	0.35	-0.46	16.36	20.39
Diff 4	3.16	1.85	15.42	-14.88	0.34	-0.07	26.98	0.17
Diff 5	3.96	1.04	14.76	21.82	0.29	0.25	20.71	-0.41
Diff 6	4.13	1.91	8.28	-7.47	0.29	0.25	20.71	-0.41
Diff 7	4.13	1.65	15.25	-15.78	0.23	-0.30	11.84	3.90
Diff 8	3.45	0.85	13.83	20.92	0.07	0.03	8.94	3.32
Diff 9	3.71	1.78	8.42	-8.37	0.23	-0.11	14.93	10.25

	Temp		Humid		Sound (dB)		Sound (hz)	
	St.dev	Mean	St.dev	Mean	St.dev	Mean	St.dev	Mean
Diff 1	2.29	0.00	7.66	0.00	6.46	0.00	6.46	0.00
Diff 2	3.51	0.00	7.74	0.00	0.09	0.00	6.48	0.00
Diff 3	3.90	0.00	7.94	0.00	0.07	0.00	7.50	0.00
Diff 4	2.31	0.00	6.45	0.00	0.23	0.00	13.75	0.00
Diff 5	3.89	0.00	6.21	0.00	0.11	0.00	14.06	0.00
Diff 6	4.27	0.00	7.46	0.00	0.11	0.00	14.06	0.00
Diff 7	4.27	0.00	4.83	0.00	0.20	0.00	5.67	0.00
Diff 8	3.53	0.00	5.04	0.00	0.06	0.00	6.22	0.00
Diff 9	3.83	0.00	6.56	0.00	0.04	0.00	6.77	0.00

Table 1, 2. Means and Standard Deviations of Normalized values when Wi-Fi is on (right) and off (left)

Discussion

- Not able to detect any effect from 2.4GHz
  - No effect measured in this study ≠ Wi-Fi is completely safe to use
    - Precautionary principle
    - Small sample size
    - Long term and/or delayed effects of exposure
- High Varroa infestation noticed in sensor data
  - Consistent with literature
- Honeybees generate humidity, temperature parallels with external fluctuations

Conclusion:

- Continuous in-hive monitoring produces rich datasets
- Sensor network proven research tool
  - Precision apiculture research largely exploratory
- Next steps: distilling key parameters
  - Determining best in-hive location(s) for sensors
    - Other parameters and technologies
      - infrared
  - Tension between apicultural research and management interests

Thanks! Questions?

Remote Sensing Data Based Crop Growth Parameters Retrieval and Crop Management Zone Delineation Research

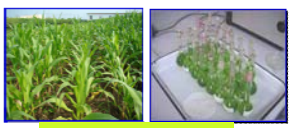
Yuanyuan Fu

Zhejiang University, China
McGill University, Canada

Contents

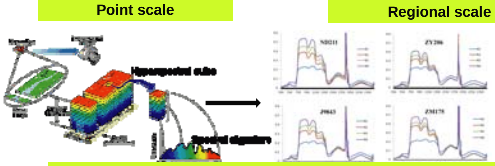
Research Background

Practical needs: crop growth and its spatial variation information



Point scale

Regional scale



Hyperspectral data: contiguous spectrum

Contents

Crop plant zone extraction based on HSI

Problem to solve

■ **Curse of dimensionality**
- ✓ Less training samples
- ✓ Poor generalization

■ **Dimensionality reduction**
- ✓ Band selection
- ✓ Feature extraction

Band selection based on scatter matrices

■ **Scatter Matrices**
- ✓ Within-class distance, inter-class distance
- ✓ No normal distribution restriction
- ✓ Extend from two classes to multi-classes

$$SB_{ij} = P_i(\mu_i - \mu_0)(\mu_i - \mu_0)^T + P_j(\mu_j - \mu_0)(\mu_j - \mu_0)^T$$

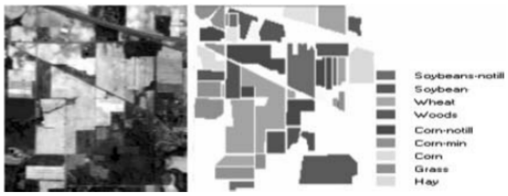
$$SW_{ij} = P_i\Sigma_i + P_j\Sigma_j$$

$$S_{ij} = trace\{SW_{ij}^{-1}SB_{ij}\}$$

$$S_{ave} = \sum_{i=1}^{M}\sum_{j>1}^{M} P_iP_jS_{ij}$$

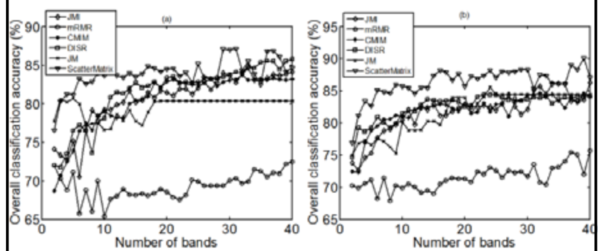
Band selection based on scatter matrices

- **AVIRIS hyperspectral image**
  - ✓ Band number 200; spatial resolution 20m
  - ✓ Agricultural area in the north of Indiana, America
  - ✓ Corn, soybean, wheat, forest and grassland



Band selection based on scatter matrices

- **Experimental results**



Band selection based on scatter matrices

- **Experimental results**

Method	Num. of bands	OA	KC	PA				
				Class 1	Class 2	Class 3	Class 4	Class 5
JMI	40	0.863	0.798	0.823	0.861	0.982	0.913	0.839
mRMR	40	0.757	0.644	0.708	0.732	0.945	0.883	0.623
CMIM	32	0.846	0.773	0.784	0.844	0.982	0.917	0.839
DISR	23	0.844	0.768	0.760	0.852	0.982	0.938	0.750
JM	24	0.856	0.788	0.843	0.843	1.000	0.899	0.818
ScatterMatrix	39	0.901	0.853	0.891	0.885	1.000	0.948	0.856

A hybrid feature extraction method

- **PCA + ScatterMatrix**
  - ✓ PCA: unsupervised feature extraction method
  - ✓ No guarantee to good class separability

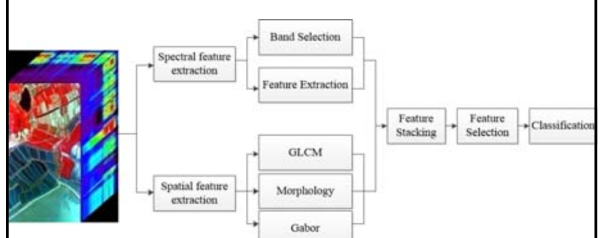
A hybrid feature extraction method

- **Experimental results**

Method	Num. of features	OA	KC	PA				
				Class1	Class2	Class3	Class4	Class5
PCA	6	0.840	0.764	0.807	0.824	0.982	0.932	0.712
ICA	15	0.827	0.746	0.822	0.822	1.000	0.843	0.792
PCA_ Scatter Matrix	13	0.865	0.799	0.820	0.878	0.982	0.909	0.746
LDA	4	0.824	0.743	0.815	0.784	0.982	0.905	0.856
NWFE	7	0.892	0.840	0.873	0.908	1.000	0.891	0.818

Fusion of spectral and spatial features

- **Multi-feature fusion**

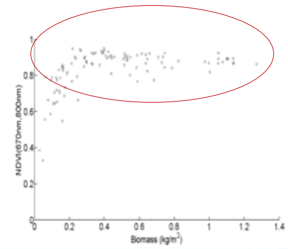


Contents

- General Introduction
- Crop Plant Zone Extraction
- Crop Growth Parameters Retrieval
- Crop Management Zone Delineation

Remote sensing data based crop growth parameter retrieval

- **Crop growth parameters**
  - ✓ LAI
  - ✓ Biomass
  - ✓ Nitrogen concentration
- **Saturation problem**



LAI VI sensitivity analyses based on PROSAIL model

- **Sensitivity function**
  - ✓ Saturation ,LAI >=3
  - ✓ R^2 and RMSE
  - ✓ Sensitivity changes according to LAI value

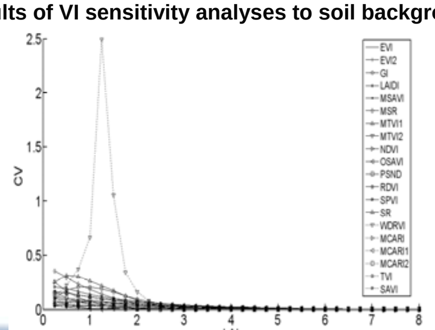
$$s = \frac{\widehat{SVI}'}{\sigma_{SVI_i}} = \frac{d(\widehat{SVI})/d(LAI)}{\sigma_{SVI_i}}$$

LAI VI sensitivity analyses based on PROSAIL model

- **Sensitivity analyses**
  - ✓ Simulated canopy spectral datasets based on PROSAIL
  - ✓ Common-used VIs
  - ✓ Sensitivity to soil background
  - ✓ Sensitivity to leaf chlorophyll
  - ✓ Anti-saturation analyses

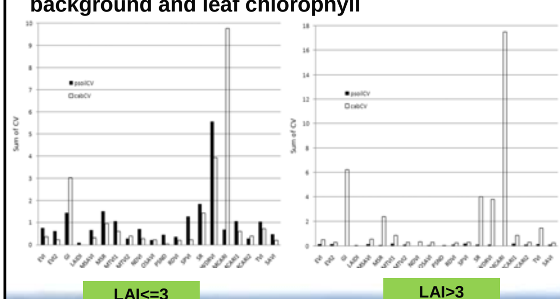
LAI VI sensitivity analyses based on PROSAIL model

- **Results of VI sensitivity analyses to soil background**



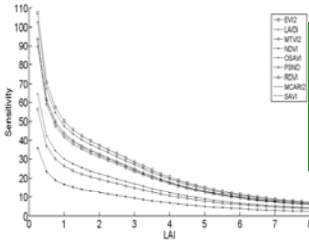
LAI VI sensitivity analyses based on PROSAIL model

- **Results of conjunction sensitivity analyses to soil background and leaf chlorophyll**



LAI VI sensitivity analyses based on PROSAIL model

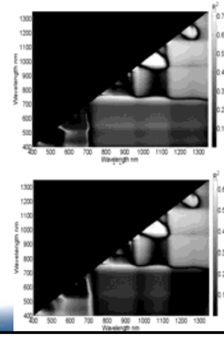
■ **Results of anti-saturation analyses**



- ❖ LAI<=3:soil background, LAIDI, OSAVI , RDVI
- ❖ LAI>3:leaf chlorophyll, EVI2, LAIDI, RDVI, SAVI, MTVI2, MCARI2

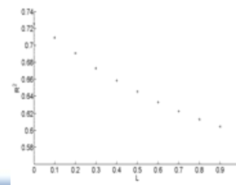
Biomass retrieval based on the combination of optimal index and band depth information

■ **Optimal hyperspectral indices selection**



$$NDVI_{narrow} = \frac{R_{\lambda 2} - R_{\lambda 1}}{R_{\lambda 2} + R_{\lambda 1}}$$

$$SAVI_{narrow} = (1+L)(R_{\lambda 2} - R_{\lambda 1}) / (R_{\lambda 1} + R_{\lambda 2} + L), L = 0.5$$



Biomass retrieval based on the combination of optimal index and band depth information

■ **Band depth information extraction**

- ✓ BD $BD = 1 - R'$
- ✓ BDR $BDR = BD / BD_{\max}$
- ✓ NBDI $NBDI = (BD - BD_{\max}) / (BD + BD_{\max})$
- ✓ BNA $BNA = BD / BD_{area}$

Biomass retrieval based on the combination of optimal index and band depth information

■ **Experimental results**

Spectral predictors	Calibration		Independent validation	
	R^2	$RMSE_c(kg/m^2)$	R^2	$RMSE_v(kg/m^2)$
Narrow band indices				
NDVI(800nm and 670nm)	0.210	0.285	0.165	0.344
SAVI(800nm and 670nm)	0.117	0.302	0.046	0.366
Optimal NDVI-like(1097nm and 980nm)	0.726	0.168	0.760	0.279
Optimal SAVI-like(1084nm and 1026nm)	0.645	0.191	0.711	0.289
Red edge position(REP)				
Maximum first derivative	0.496	0.228	0.240	0.333
Linear interpolation	0.567	0.211	0.193	0.350
Inverted Gaussian model	0.571	0.210	0.221	0.341

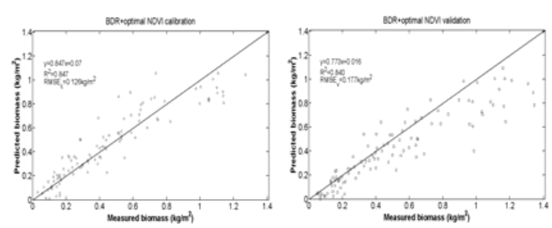
Biomass retrieval based on the combination of optimal index and band depth information

■ **Experimental results**

Method	No. of factors	Calibration		Independent validation	
		R^2	$RMSE_c(kg/m^2)$	R^2	$RMSE_v(kg/m^2)$
BD	4	0.792	0.146	0.696	0.211
BDR	5	0.830	0.132	0.735	0.193
NBDI	4	0.781	0.150	0.622	0.233
BNA	4	0.783	0.149	0.687	0.211

Biomass retrieval based on the combination of optimal index and band depth information

■ **Experimental results**

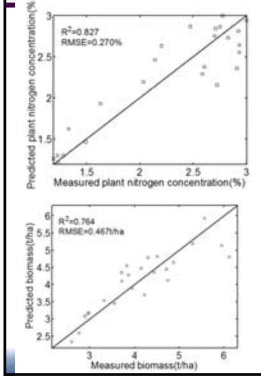


NNI Retrieval and wheat GPC estimation based on NNI

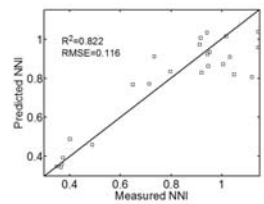
■ **Canopy spectrum->NNI->wheat GPC**

- ✓ No direct relationship between spectrum and GPC
- ✓ Relationship between nitrogen concentration and GPC
- ✓ NNI: ratio of plant nitrogen concentration and critical plant nitrogen concentration
- ✓ NNI retrieval: the retrieval of plant nitrogen concentration and above ground biomass

NNI Retrieval and wheat GPC estimation based on NNI

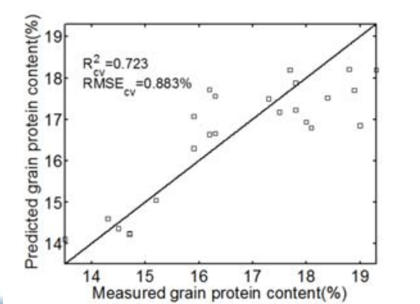


■ **NNI retrieval results**



NNI Retrieval and wheat GPC estimation based on NNI

■ **GPC estimation results**



Crop growth parameters retrieval and monitoring based on CASI HSI

■ **Study area and datasets**

- ✓ Heihe basin in China
- ✓ CASI HIS: band number 48, spatial resolution 1m
- ✓ LAI samples: corn (11),vegetables (3)

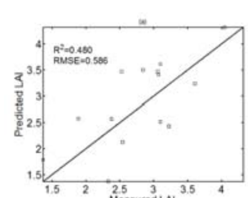
LAI VI sensitivity analyses based on PROSAIL model

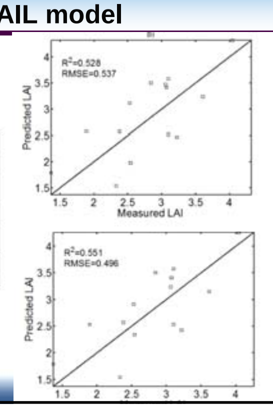
■ **Lookup table based LAI retrieval**

- ✓ Simulated canopy spectral datasets based on PROSAIL
- ✓ Look up table : easy to realize, more stable
- ✓ Average of multi-solutions: ill-posed problem

LAI VI sensitivity analyses based on PROSAIL model

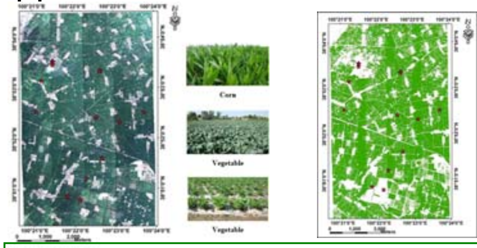
■ **Experimental results**





LAI VI sensitivity analyses based on PROSAIL model

■ **Crop plant zone extraction**

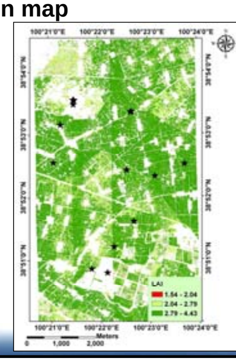


❖ Non-vegetation region removal: NDVI threshold

❖ Band selection: 483nm,554nm and 726nm, SVM

LAI VI sensitivity analyses based on PROSAIL model

■ **LAI distribution map**



Thanks!